IGNEOUS INTRUSIONS IN THE NEIGHBORHOOD OF THE BLACK HILLS OF DAKOTA.

On the northern border of the Black Hills of Dakota, and situated partly in Wyoming, there are about a dozen hills of igneous rock, which not only add variety and beauty to the picturesque region where they occur, but are unique topographic features and furnish examples of a type of igneous intrusions that does not seem to have been clearly recognized.

The hills referred to, are known in the general order of their occurrence from east to west, as Bear Butte, Custer Peak, Terry Peak, Black Butte, Crow Peak in South Dakota, Inyan Kara, the Sun Dance hills, Warren Peaks, Mato Tepee or Bear Lodge, and the Little Missouri buttes in Wyoming.

Only a few of these hills have been examined by me, but such observations as I was able to make together with the descriptions given by N. H. Winchell[1] and Henry Newton[2] of those not visited, show that they all have a common history and may be classed in a single group.

Each of these hills owes its existence to the injection from beneath of a column of molten rock into stratified beds, and the subsequent removal of the enclosing sedimentary strata so as to expose, with one exception, the inner core of plutonic rock. They differ from the laccolites described by G. K. Gilbert[3], in the fact that the molten rock did not spread out horizontally among the stratified beds so as to form "stone cisterns,"

[1] Geological Report. In report of a reconnoissance of the Black Hills of Dakota made in the summer of 1874, by William Ludlow, Washington (Engineer Department, U. S. A.), 1875, 4to, pp. 21–66.

[2] Geology of the Black Hills (edited by G. K. Gilbert). In report on the geology and resources of the Black Hills of Dakota, by Henry Newton and Walter P. Jenney, Washington (Department of the Interior), 1890, 4to, 1–222.

[3] Report on the Geology of the Henry Mountains; Washington (Department of the Interior), 1877, 4to, pp. x.+160, Plates I.–V.

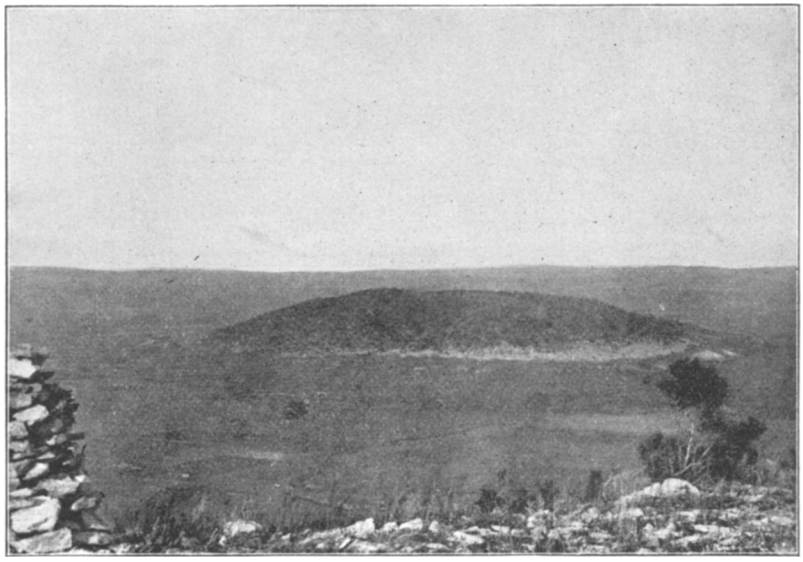

FIG. A.—Little Sun Dance Dome from the summit of Sun Dance Hill.

FIG. B.—Inner escarpment of limestone encircling the summit of Sun Dance Dome.

although some of the hills named, which had not been examined by the writer, may reveal this structure when more thoroughly examined. They differ, also, from volcanic necks like those of New Mexico described by Captain Dutton,[1] to which some of them have a superficial resemblance, in the fact that the injected rock did not reach the surface so as to form either coulees or cinder cones. As they are composed of igneous matter forced into sedimentary strata and have a plug-like form, it will be convenient to call them *plutonic plugs.*

In the hills examined by the writer the structure has been revealed in varying degrees by denudation, so that an examination of a few examples furnishes a series of illustrations ranging from an unbroken dome of stratified rock arching over the summit of a concealed mass of plutonic rock, to imposing towers of columnar rhyolite several hundred feet in height, exposed by the removal of the softer strata into which they were intruded.

The first in this series is Little Sun Dance dome. This is a regular dome of stratified rock, about a mile in diameter, the outer layers of which have been removed and the inner ones of resistant limestone, deeply gashed by erosion, but not dissected sufficiently to expose the top of the igneous plug which presumably exists beneath.

The other extreme is shown by Mato Teepee. In this instance the arch of stratified rock which once surmounted the summit of the plutonic plug has been completely removed and the surrounding strata eroded away.

The rocks of which the plutonic plugs are composed have been studied microscopically by J. H. Caswell[2] and found to be rhyolite and sanadine-trachyte.

The rock composing the several hills is closely similar in general appearance and in chemical composition and crystalline structure. It is described in the report just referred to, as light-

[1] Mount Taylor and the Zuni Plateau. In 6th Annual Report of the U. S. Geological Survey, 1884–5, Plates XI.–XXII.

[2] Microscopical Petrography of the Black Hills of Dakota. In report of the geology and resources of the Black Hills of Dakota, by Henry Newton and Walter P. Jenney, Washington, pp, 489–527, Plates I.–II.

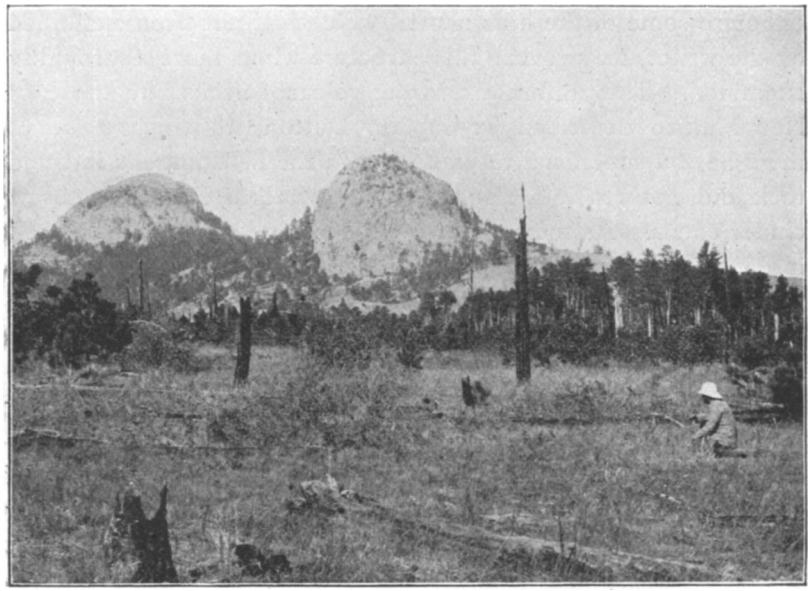

FIG. A.—Sun Dance Hill from the southwest.

FIG. B.—Little Missouri Butte from the east.

colored, compact and usually coarsely crystalline; and contains prominent crystals of sanadine, quartz, biotite and hornblende.

In the hills examined by the writer, namely, the Sun Dance hills, Mato Teepee and the Little Missouri buttes, the rock appeared to be of the same character in each instance. In hand specimens it was impossible to distinguish any essential difference. For a more exact description of the rocks in question the reader is referred to Mr. Caswell's report which contains the results of the only systematic study of them that has been made.

The stratified beds through which the plugs have been forced, vary in age from the Potsdam to the middle of the Cretaceous. In a conglomerate discovered by W. P. Jenney[1] at the base of the Miocene in the neighborhood of the Black Hills, pebbles of igneous rock were found which must have been derived from the hills now claiming our attention. The date at which the plugs were formed is therefore somewhere between the Middle Cretaceous (Fort Pierre group), which was disturbed and altered by their intrusions; and the base of the Miocene, at which date they were exposed to erosion and contributed pebbles to neighboring streams.

In discussing the date of the origin of these rocks, Newton[2] observes that the interval mentioned above, witnessed the deposition of the Niobrara, Fort Pierre, Fox Hill, Judith River and Fort Union terrains, which represent a total depth, in the upper Missouri region, of about 4000 feet of sedimentation. The date of the igneous activity is therefore very far from being definitely established, and its relation to the main Black Hills uplift is not determined. The igneous rocks may have been in place and even ancient when the elevation of the Black Hills began, or they may have been forced up while the greater movement was in progress.

With this introduction, such facts of geographical and geological interest as are available concerning these remarkable intrusions will be presented.

[1] Geology of the Black Hills, p. 220.

[2] *Ibid.*, 220.

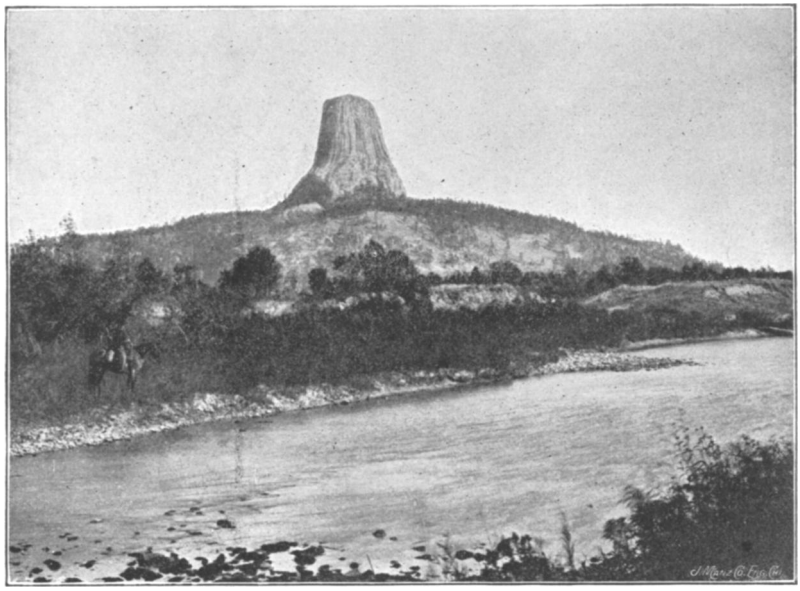

FIG. A.—Mato Teepee from the valley of the Belle Fourche.

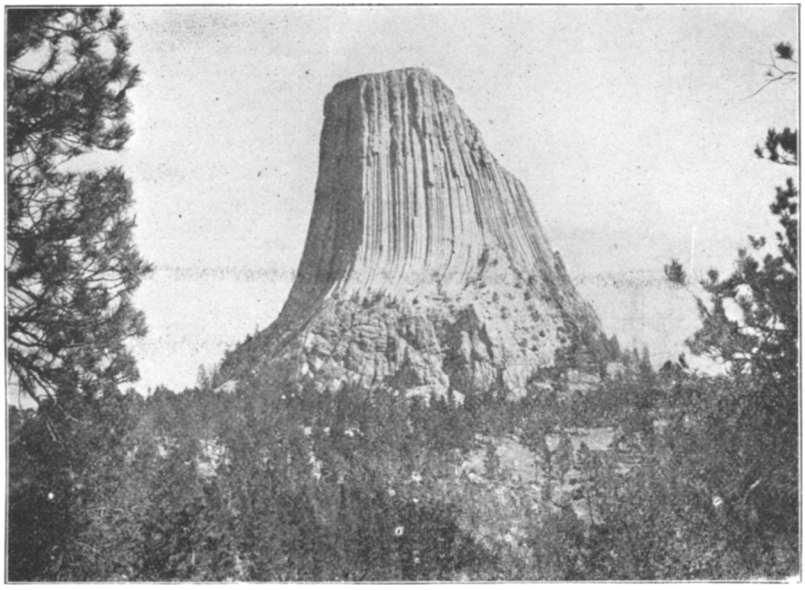

FIG. B.—Mato Teepee from the southwest.

Little Sun Dance dome.—This hill, sometimes called Green Mountain, is situated about two miles northeast of the town of Sun Dance, the county seat of Custer county, Wyoming, and about three miles north of a larger uplift of the same character, known as Sun Dance hill.

A view of Little Sun Dance as seen from the topographic monument on the summit of its more imposing companion, is given in Fig. A, Plate I. This dome is remarkably regular from whatever direction it is seen, and is composed of stratified rocks which have without question been elevated by a force acting from below directly upward. The summit of the hill consists of Carboniferous limestone, the crown being an unbroken dome. About this inner dome and dipping sharply in all directions are strata of purplish limestone belonging to the Red Beds or Triassic system. This resistant layer has a thickness of about twenty feet, and was once continuous over the top of the dome, but has been removed from the summit by erosion, and several radiating gorges cut by streams in the portion of the envelope which remains. Between the drainage lines the strata extend far up on the sides of the dome so that the edge of the outcrop when followed about the hill forms a zigzag line. As described by Newton, the exposed edge of this limestone resembles the broken edge of a piece of paper that has been punctured by a sharp pencil. Although the strata have been bulged upward, they have not been shattered, the apparent radial breaks being due entirely to erosion. Resting on the limestone, are soft, easily eroded shales, a hundred feet or more in thickness. The position of this bed is indicated about the base of the hill by a smooth, grassy valley a few hundred feet in breadth. On the outer side of this valley is a rampart, more or less well defined, of sandstone layers, which dip away from the dome in all directions but present a steep inner escarpment. The sandstone and shale belong, together with the purple limestone, to the Red Bed system, and are the highest or youngest strata exposed in the immediate vicinity.

The streams which have eroded deep trenches in the sides of

the dome, radiate from its center and, with one exception, are active only during wet weather. At the head of a deep, wooded gorge which leads northward from near the center of the uplift, there is a small spring from which flows a perennial rivulet. A view looking down this channel is shown in Fig. B, Plate I. The rock forming the cliffs is purple limestone and shows the character of the zigzag escarpment that Newton compares with the torn edges of the paper through which a pencil has been forced.

An examination of the bottoms of the drainage channels on the summit and sides of the Little Sun Dance dome, and of the débris with which they are partially filled, failed to reveal even a fragment of igneous rock.[1]

The most interesting facts connected with the geology of the Little Sun Dance dome are, that the rocks were elevated by an extremely local force acting from below upward, and that the strata which suffered deformation were not fractured, or sensibly metamorphosed, during the process. The absence of fractures in the crown of the dome, as well as the vast amount of erosion which is known to have taken place in the region in which it is situated, show that the bending of the rocks must have taken place under a great weight of superincumbent strata.

Sun Dance hill.—This hill is not only higher and larger than the one just described, but differs from it widely in its topographic form. As seen from Little Sun Dance, it represents a bold scarp to the west and declines more gently and with many undulations in other directions. The western scarp (Fig. A, Plate II) is composed of plutonic rock and has steep talus slopes at its base. The flanks of the hill, especially on the east, are composed of Red Beds, somewhat upturned. These strata extend entirely about the central core of intruded rock and slope away from it at low angles in all directions.

A geologist on visiting Sun Dance hill, after examining its smaller neighbor, would say at once that the two uplifts are very similar in many ways. In Sun Dance hill the intruded rock was

[1] This hill is marked as igneous on the map accompanying Newton's report on the geology of the Black Hills.

forced to a higher level than the present crown of the Little Sun Dance dome, and has been well exposed by the removal of surrounding strata. As these hills stand near together on the same plain, it is evident that they have been exposed to the same erosive agencies. The larger hill is higher for the reason that the plug forming its center was forced to a higher level in the stratified beds and is also of greater diameter than the similar plug which presumably caused the upheaval of the smaller hill. It is also to be noted that the sedimentary beds surrounding the larger intrusion show less disturbance than those around the smaller uplift, which has been dissected less deeply in reference to the top of the column of igneous rock. This indicates that the greatest amount of disturbance among the stratified beds occurred near the summits of the intruded columns.

Mato Teepee.—This remarkable tower has been described very fully by Newton,[1] and to his account of it we are indebted for the measurements here used. It stands on the west bank of the Belle Fourche River, about twenty-two miles northwest of the Sun Dance hills, and six miles southeast of the Little Missouri buttes, next to be described.

As stated by Newton, the name "Bear Lodge" is used on the earliest maps of the region, although more recently it is said to be known among Indians as "the bad god tower," or in better English, "the Devil's tower." Mato Teepee, meaning Bear lodge, seems to have been the original Indian name and will be used in this paper.

Something of the impressive grandeur of this lonely column may be gathered from the accompanying pictures. Fig. A, Plate III., is reproduced from a photograph taken on the banks of the Belle Fourche about two miles in a direct line south of the tower. Even at this distance the clustering columns that combine to form the structure may be easily distinguished. Another view, showing the columnar structure still more clearly is also given on Plate III., which is from a photograph taken about a quarter of a mile southwest of the tower.

[1] Geology of the Black Hills, pp. 200–202, and frontispiece.

The platform surrounding the base of Mato Teepee as seen in Fig. A, Plate III., is not a remnant of a coulee of lava or the remains of an ancient cinder cone, as might be supposed from a distant view, but is composed of sandstones and shales belonging to the Red Beds and the Jurassic formations. The stratification of these beds, even up to the base of the tower, is horizontal and undisturbed. Some change in texture, however, may be observed in the strata in the immediate vicinity of the intruded rocks, showing that they were hardened and somewhat metamorphosed when the igneous material was forced in among them.

When Mato Teepee is seen from almost any locality in the valley of the Belle Fourche within a radius of several miles, one is not only forcibly impressed by the grandeur of the monumental form that dominates the landscape, but is delighted by the brilliant and varied colors of the rocks forming the sides of the valley and the immediate base of the tower. The Red Beds in the lower portion of the river bluffs show many variations of pink and Indian red, and have been sculptured into architectural forms of great beauty. The less brilliant Jurassic sandstones resting upon them and forming the upper portions of the bluffs, serve to carry the eye from the rich colors below to the dark forest of pines that grow above and to the still more somber precipices of the great tower which always appears in bold relief against the sky.

The platform on which Mato Teepee stands is 500 feet above the river, while the tower proper rises almost vertically 626 feet above it. The tower is nearly rectangular in cross section; the width at the summit from north to south, being 376 feet, and the width at the base 796 feet.[1] The shaft of the column is composed of clustered prisms which extend from base to summit without cross divisions. These prisms are usually pentagonal, although other forms are not uncommon. Most frequently they have a diameter of from eight to ten feet. Each prism tapers somewhat toward the top, and near its upper extremity is cracked

[1] Geology of the Black Hills, p. 201.

and discolored by weathering. At the base of the tower the columns in most instances, except at the southeast corner, curve abruptly outward, and, at the same time, increase somewhat in size. On the west side they become nearly horizontal and are soon lost to sight beneath accumulations of débris. Near the base of the tower, just above the treetops, as seen in Fig. B, Plate III., the rock loses its columnar structure, becomes massive and breaks with an irregular fracture. On the sides of the tower there are a few places where the lower portions of individual prisms have fallen away, leaving the upper two or three hundred feet still in place. In such instances one has a good view of a section of the prisms, which are seen to be four, five or six-sided.

Owing to the abrupt outward curvature of the columns at the west base of the tower, the fragments that have fallen from above have been thrown farthest out on that side and now form an extremely rugged talus in which fragments of huge columns lie piled in endless confusion one on another, suggesting the ruins of some mighty temple.

As shown in the accompanying illustrations, the sides of the tower are nearly perpendicular. This fact is still more impressive in nature, especially when one stands at the base of the great prisms, each of which is an uniform column over 500 feet high, and looks upward. The strongest and most experienced mountain climber must pause when he has scaled the rugged cliffs which form the immediate base of the tower and gains the point where the individual prisms make their abrupt curve and ascend perpendicularly. Beyond that point no man has ever reached, and, it is safe to say, never will, unaided by appliances to assist him in climbing.

To gain a comprehensive view of Mato Teepee and of its relations to neighboring cliffs and plateaus, one should go about two miles west from the tower and ascend to the top of the table-land which has been cut away to form the valley of the Belle Fourche. Standing on the border of this table-land which rises more than 1000 feet above the silvery thread marking the course of the river in the valley below, one is a little lower than the

top of the tower which is the most prominent object in the landscape. On looking west from this point of view, it is at once apparent that the observer is on the immediate border of a tableland which stretches away far beyond the limits of view. On this plateau and four or five miles distant, stands a group of three hills known as the Little Missouri buttes.

It requires but a glance from almost any commanding position in the neighborhood of Mato Teepee, to show that the valley of the Belle Fourche has been eroded in the flanks of a broad uplift, which culminates several miles to the east in a great dome-shaped elevation known as Mount Warren. In fact the rocks removed to form the valley hardly interrupt the gentle sweep of the sky-line as one follows the profile of the land on looking southwest. It is at once apparent to every observant person who looks down on the valley of the Belle Fourche from a commanding station, that the stratified rocks which form the bordering bluffs of the valley were once continuous, and that the whole depression has been formed by erosion. Mato Teepee rises from the bottom of this valley and must at one time have been surrounded by the strata that have been carried away. It is a monument of erosion not unworthy of the great events it commemorates. Restore the rocks which have been removed in order to form the valley up to the level of the cliffs on which the reader is supposed to stand, and Mato Teepee would be nearly buried. A thousand feet of rock have been removed to form the valley about it, but this does not represent the entire amount of the erosion that has taken place. This is shown by the history of the Little Missouri buttes which stand on the plateau stretching west from Mato Teepee. These hills are of the same nature as the great tower in the valley below, and were intruded among sedimentary strata that rested on the platform above which they now rise. As their tops are more than 500 feet above the plateau, it is evident that more than this thickness of rock has been removed in order to expose them.

As erosion goes on, the rocks forming Mato Teepee will crumble and be carried away by the stream which is even now

encroaching upon its base, while the plugs forming the Little Missouri buttes will become more and more prominent as the stratified rocks are removed from about them, and when the valley of the Belle Fourche shall have been broadened so that the waters of the river wash their bases, will form towers of the Mato Teepee type.

The total amount of erosion that has taken place in the region about Mato Teepee cannot be accurately determined from the study of the local topography, but is certainly greater than the vertical distance from the bottom of the valley to the topmost crag of the Little Missouri buttes, that is, over 1500 feet. As shown by Newton, more than 4000 feet of Cretaceous and Tertiary strata have been removed from the Black Hills region.

The Little Missouri Buttes.—These buttes, as already stated, are formed of igneous rocks of the same character as those composing the Sun Dance hills and Mato Teepee. They are three in number and occupy the angles of a triangle, the distance between them being about three-fourths of a mile. Among the Indians they are said to be designated by a term which means "the buttes that look at each other."

The summits of the Little Missouri buttes are of bare rock, sometimes showing a columnar structure, and resemble the summit of Mato Teepee, except that they are less flat. The junction of the igneous rock with the surrounding Cretaceous sandstone is obscure, but the stratified rocks are well exposed near at hand and gives no indication of having been disturbed in bedding or altered in texture. Newton[1] reports that in one or two localities near the base of the buttes a tuff-like rhyolitic breccia was found in which were imbedded fragments of both sandstone and rhyolite.

The view of the buttes here presented, Plate II. (in which only two of them are seen, the third being to the left and beyond the field of view) is from a photograph taken at a locality on the Cretaceous plateau about a mile distant from the nearest hill in the direction of Mato Teepee.

[1] Geology of the Black Hills, p. 203.

The Cretaceous sandstone surrounding the base of these buttes is the youngest of the stratified rocks which come in immediate contact with the igneous intrusions we are studying, and presuming that all the igneous rocks are of the same date, records the upper limit as nearly as can be determined, to be placed on estimates of the time of their origin. That is, they are younger than the Middle Cretaceous.

Inyan Kara.—This lone butte stands in Wyoming on the west side of the main uplift of the Black Hills. It has not been seen by the present writer except from a distance but has been described by both Winchell and Newton. As Newton's visit was the more recent we quote his description almost entire:[1]

Its name first appeared on a map published by Lieut. Warren in 1858, and as translated for him, signifies "the peak which makes stone." Its summit is 6600 feet above the sea, and has an elevation of 1300 feet above the bed of the Inyan Kara Creek near by. The igneous mass of the peak occupies the center of what in form resembles a crater, for separated from it by an annular valley there is an encircling ridge or rim whose top is 500 feet below the summit of the peak. This rim is formed of Red Bed limestone rising up from under the surrounding red clays at an angle of about 40° and completely encircling the peak except at a narrow break on the northeast side where the drainage escapes. The limestone wraps around the outer slope of the peak like a cloak, conforming to all local changes of dip and is without fracture. The upper red clays of the Red Beds lay up against this limestone, and in conformity with it dip away in all directions. On the inside of the rim is the annular valley, surrounding the igneous nucleus and having a width, from rim to center of peak, of from one-half to three-fourths of a mile. It has evidently been formed by the denudation of the easily eroded strata beneath the limestone.

From the midst of the crater-like depression the peak rises so abruptly that there is but one side with an easy slope for climbing. The summit is a broad but very irregular area, whose

[1] Geology of the Black Hills, pp. 197–199.

larger dimension has a bearing of about 30° West of North and upon which the rock is well exposed. It is a hard, highly feldspathic trachyte, and on weathered surfaces large and well formed crystals of feldspar were seen in great abundance, giving the weathered mass a porphyritic appearance. Its mass is notably magnetic. The rock shows well marked cleavage or jointing planes, nearly vertical, in two series. The first runs toward the northwest and the second towards the west, dividing the rock into prisms and producing a quasi-columnar structure.

Though on such a large scale, the entire upheaval being probably two or three miles in diameter, the peak has essentially the structure of the Sun Dance hills. Among the uplifted beds surrounding Inyan Kara no strata were recognized excepting Red Bed limestone and the underlying, impure, reddish sandstone, and beyond the immediate base of the outer slope no disturbance was indicated. Indeed, the red arenaceous clay is too nearly structureless to retain readily such evidence.

The high angle at which the stratified rocks surrounding the base of Inyan Kara dip away in all directions from the central core, shows that there was more disturbance caused by this intrusion than in any of the similar examples previously described in this paper. The igneous rock was also forced to a higher level than in the Sun Dance hills, and was greater in mass than in any of the similar hills in the neighboring part of Wyoming, with the exception of Mount Warren.

Complete as is the exposure of the igneous rock in Inyan Kara, it is to be remarked that no expansion of the central plug so as to form a coulee or a laccolite, is mentioned by the geologists who have examined and described it.

Bear Butte.—On the northeast side of the Black Hills and about six miles east of the town of Whitewood, there is another conspicuous butte, similar in many ways to Inyan Kara. This hill, known as Bear Butte, rises from Middle Cretaceous shales but is surrounded at its immediate base by older rocks which dip away in all directions. It has been described by F. V.

Hayden,[1] N. H. Winchell[2] and Henry Newton,[3] and from these descriptions the following has been compiled.

The butte rises 1200 feet above the surrounding plain and attains an elevation above the sea of 4570 feet. As seen from the north, it is a simple cone, but from the east and west summit appears as a ridge several hundred feet in length, with a trend about North 40° West. The strata which are exposed about its base and dip away from it in all directions, are composed of rocks of all ages from the Middle Cretaceous to the Potsdam, inclusive. A dense quartzite, probably of Potsdam age, occurs at the immediate base of the butte in vertical strata, but does not form a continuous circular outcrop.

The rock of which the butte proper is composed is very similar if not identical with that forming Inyan Kara, Bear Lodge, etc. It is crossed by cleavage plains but is not columnar. When freshly broken it is gray in color but when weathered it appears nearly black. The débris in the immediate vicinity of the butte is so abundant that good exposure of the stratified rocks surrounding its base are seldom seen. The harder beds in these strata, however, influence the relief sufficiently to show the presence of an encircling rampart of the same character as the much more conspicuous one, about the base of Inyan Kara. Denudation has stripped the central plug of igneous rock of its enveloping stratified beds almost as completely as in the case of the great tower in the valley of the Belle Fourche.

Crow Peak.—This peak is situated in the northern part of the Black Hills, about five miles west of the town of Spearfish, and rises to an elevation of approximately 1,500 feet above bottom of the Red Valley, which skirts its northern base.

It is described by Newton,[4] as a pustular outbreak of igneous rock through Red Bed limestone. As seen from the west it appears as two peaks closely united; the southern one is the

[1] Trans. Amer. Philo. Soc., Vol. XII., n. s., 1863, p. 28.

[2] Reconnoissance in the Black Hills, pp. 55–56.

[3] Geology of the Black Hills, pp. 195–197.

[4] Geology of the Black Hills, pp. 194–195.

rhyolite core, while the northern one is a portion of a rampart of sedimentary beds which once entirely surrounded it. This hill, like the others in the series to which it belongs, owes its existence, if the present writer's views are correct, to the intrusion of a plug of igneous rock vertically upward through nearly horizontal sedimentary beds and the subsequent exposure of the intrusive rock by erosion.

Terry and Custer Peaks.—These are other prominent landmarks in the northern portion of the Black Hills. They have been described by Newton,[1] as pustular outbreaks of igneous matter and belong to the series of intrusions to which attention is here directed, but so far as one can judge from the published descriptions, they offer no important features not already noticed in this paper.

Warren Peak.—This is the largest and in fact the only truly mountainous mass of igneous rock on the outskirts of the Black Hills, and may differ materially in the mode of its formation from the plugs of crystalline rock we have already noticed. Its broad extent and the manner in which the surrounding stratified rocks dip away from it in all directions, seems to indicate that it is a true laccolite, very similar to those of the Henry Mountains. The description given below is copied from Newton.[2]

Warren peaks are the crowning points of the "Bear Lodge Range," an elevated, broken plateau between the Redwater valley and the Belle Fourche. The peaks are not remarkably prominent, but their total elevation above the sea, 6830 feet, is equal to that of some of the principal peaks in the central portion of the Black Hills, while their height above the Red Valley immediately south, is about 1800 feet. The trachytic area to which they belong is the largest of the whole group, and covers fifteen or twenty square miles. Around this the strata of the sedimentary series are uplifted and arranged in concentric circling outcrops, so as to make a sort of miniature copy of the hills. The trachytic nucleus has an extension from northeast to

[1] Geology of the Black Hills, pp. 192–194.

[2] Geology of the Black Hills, pp. 199–200.

southwest of about eight miles, and a width of two or three miles. Its surface consists of high, rounded, grass-covered hills, with little or no timber, and from this rise the two or three more elevated points to which the name Warren peaks has been applied. These more central points are surrounded by smaller and less prominent peaks, which are separated by deep ravines or gulches forming the lines of drainage. Besides this great nucleal mass of igneous rock, several outbursts, very local in character, were observed in the zone of encircling strata. The rock is a trachyte, dark gray in color, and containing frequently large and perfect crystals of sanadine which give it a porphyritic character. Small crystals of mica and hornblende are also prominent, and the rock yields more to weathering than that of some of the other peaks. In different portions of the district the rock varies somewhat in its character, though evidently of the same general nature.

The encircling zones of sedimentary rocks include the Potsdam below and the Jura above. Their dip is quaquaversal and is usually quite regular, the angle varying from 20 to 30 degrees.

The Potsdam sandstone which immediately overlaps the base of the igneous mass has been greatly metamorphosed. When the rock was shaly it has been changed into a hard fissile slate, scarcely recognizable as of sedimentary origin; and the pure sandstone strata have been converted into compact quartzite often of a very white color. In several places the igneous matter seems to have penetrated between the strata, which are scarcely distinguishable from the injected rock, and in many cases the metamorphosis appears to have been performed by the action of heated waters, for the sandstone was found penetrated irregularly by well-formed crystals of feldspar. On the west side, near the middle of the formation were found layers of argillaceous sandstone covered by large branching fucoids peculiar to the Potsdam, and some of the upper layers of the sandstone are perfectly riddled with Scolithus holes. The Potsdam, Carboniferous and Red Beds are well exposed in many of the canyons which radiate from the central area carrying the drainage eastward to the Red-

water, or westward to the Belle Fourche. On the south and east, facing Sun Dance hills, the Red Bed limestone forms the outer slopes, dipping under the red clay of the Redwater Valley. On the north and west, however, the Jura is well exposed and capping this the Dakota sandstone.

Though on a grander scale and exposing a larger area of igneous rock than the other neighboring centers of intrusion, the Warren peaks show the same character of pustular eruption.

In a recent paper on the geology of the Black Hills, W. O. Crosby,[1] has devoted a few pages to the consideration of the igneous intrusion described in this paper, in which it is claimed that they are true laccolites. He also presents reasons for concluding that the hypothesis of "Pustular Eruptions," advanced by Newton is not warranted by the facts.

As I am unfamiliar from close inspection with the larger igneous masses of which Warren, Terry and Custer peaks are leading examples, I am unable to offer an opinion as to whether they are laccolites or not. Their great size and the manner in which the surrounding sedimentary beds have been disturbed and altered in their vicinity, certainly seem to indicate that such was their mode of origin. In the case of the Sun Dance hills, Mato Teepee and the Little Missouri buttes, however, which I have examined and also in the case of Inyan Kara and Bear Butte, which I have seen from a distance, and of which detailed descriptions have been published, the evidence does not sustain the assumption that they are laccolites.

The absence of volcanic débris except in the immediate vicinity of these hills, indicates that the intruded rock did not spread widely among the stratified beds or overflow the surface. This, as well as the fact that in a series of examples ranging through all degrees of erosion from the unbroken dome of Little Sun Dance hill to Mato Teepee with its majestic tower over 600 feet high, and Bear butte, 1200 feet high, neither of which exhibit evidence of laccolitic expansion, seems sufficient to prove

[1] "Geology of the Black Hills of Dakota." Boston Soc. Nat. Hist., Proc., Vol. XXIII., pp. 488–517.

that they cannot be referred to the class of intrusions that has its type in the Henry Mountains.

What precise mode of origin Newton had in mind when he compared these intrusions to bubbles in a viscid lava mass, is not clear. As the nature of laccolites was not understood at the time of his exploration, a comparison with that form of intrusion could not be made.

That the magma composing the hills described in this paper was cooled slowly at a considerable distance below the surface, and consequently under great pressure, is indicated by their geological associations and is proven also by the character of their crystalline structure. They are coarse grained or porphyritic, instead of being glassy and imperfectly crystallized. In no instance has the rock assumed the form of obsidian, pitchstone, pearlite, etc., or been expanded into scoria and pumice, as one would expect had the magma cooled at the surface.

None of the plutonic plugs examined by me are associated with dikes or faults. In fact dikes appear to be wanting in the Black Hills region, since they do not seem to be mentioned by any of the geologists who have written concerning it. It is reasonable to suppose that the magma which rose from below and formed the plug-like intrusions described above, found its way through fissures in the lower series of stratified rock, but proof that this was the case is wanting. How the stratified beds below the domes that covered the plugs were displaced, or perhaps fused, so as to furnish room for the passage of the intruded material, is not clear.

A comparison of the structure of the Sun Dance hills, Inyan Kara, etc., which are from one to two or three miles in diameter, with the structure of the dome that once covered Warren Peak, and had a diameter in one direction of two to three miles, in another direction of about eight miles and a height of two or three thousand feet; and still again with the structure of the vastly greater dome from which the Black Hills, as we know them, were sculptured, brings out striking similarities. Had no erosion taken place since the Black Hills uplift began, as is shown

in a contour map by Newton and Gilbert,[1] it would now form a great, elongated dome, about 80 by 160 miles in diameter, and rising 7000 feet above the encircling plain. The central core of this vast dome is composed of schist and granite, from which the surrounding sedimentary beds dip away in all directions in the same manner as they do about the Sun Dance hills.

Great as is the Black Hills dome, it is far surpassed in size by a similar uplift forming the Big Horn Mountains, rising some 180 miles to the westward, and by several of the ranges in the Park Mountains, Colorado.

Some of the thoughts suggested by these and other comparisons, with reference to the origin of great domes in a broad region of horizontal rocks, will be presented in a future paper in this JOURNAL.

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[1] Geology of the Black Hills, Pl. *cf.* p. 208.